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THERMAL EXPANSION OF SOME SILICATES OF ELEMENTS IN GROUP II OF THE PERIODIC SYSTEM

By R. F. Geller and Herbert Insley

ABSTRACT

A ceramic body having the unusually low average coefficient of linear thermal expansion of 0.53×10^{-6} in the range 0° to 200° C., reported by W. M. Cohn, was investigated, and it was found that this material is composed essentially of the mineral cordierite. The investigation was amplified to include thermal expansion determinations for some compounds of other elements in Group II of the periodic system. The data obtained indicate that zinc orthosilicate, celsian and beryl appear worthy of consideration by those interested in the development of bodies having low coefficients of thermal expansion.

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I. INTRODUCTION

A ceramic body having the unusually low coefficient of linear therma. expansion of 0.53×10^{-6} in the temperature range 0° to 200° [1] has been reported by W. M. Cohn.[2] Science and industry are searching continually for compositions of low thermal dilatation, and applications of otherwise satisfactory materials may be hindered by their comparatively large volume changes when heated and cooled. For this reason, the ceramic body reported by Cohn is of particular interest.

The present report contains the results of a short study in which Cohn's findings are duplicated. The study was amplified to include linear thermal expansion determinations for some silicates of other elements in Group II of the Periodic Table.

II. MATERIALS AND METHODS

The specimens of series A (Table 1) were made of a body composed of 43 per cent talc (approximately 95 per cent $3MgO\cdot4SiO_2\cdot H_2O$), 35 per cent Florida kaolin (93 to 95 per cent kaolinite), and 22 per cent electric furnace corundum (99 per cent Al_2O_3) dry sieved through a No. 200 sieve. This body was intended as a duplicate of

[1] Temperatures are given in °C., throughout this report.
[2] Ber. der Deut. Ker. Gesell., vol. 10, p. 271, June, 1929, and vol. 11, p. 62, February, 1930, and Ann. Physik, vol. 4, p. 493, 1930.

the body described by Singer [3] as typical of those investigated by Cohn.

The specimens of series B (Table 1) were made of a body composed of 39.5 per cent talc, 47.2 per cent Georgia kaolin (96 to 98 per cent kaolinite), and 13.3 per cent anhydrous Al_2O_3 obtained by heating reagent quality aluminum nitrate.

The specimens of series C (Table 1) were made of a wet ground mixture of 24 per cent of reagent quality basic magnesium carbonate ($Mg(OH)_2 \cdot (MgCO_3)_4$), 45 per cent of potters' flint less than 10μ in size, and 31 per cent of Al_2O_3 obtained as described for series B.

No attempt was made to produce specimens containing only one crystal phase. Specimens containing a minimum of 90 per cent of the crystalline compound investigated, as determined by petrographic examination, were considered of sufficient purity to establish the approximate thermal expansion of that compound.

Unless otherwise stated, the various heat treatments described in Tables 1 and 2 and in the text were made in electrically heated furnaces, the resistors being 80 per cent platinum-20 per cent rhodium wire.

Expansion determinations were made by the interferometer method.[4] The specimens of series A and B (Table 1) were molded and heated in the form of disks about 2 cm in diameter, 0.3 cm in thickness, and with a hole through the center about 0.7 cm in diameter. Three small cones or "feet" protruded from opposite points on each side. The over-all height varied between 0.50 and 0.75 cm. Irregularly shaped pieces, approximately pyramidal in form and from 0.50 to 0.75 cm in height, were used for expansion determinations of the other materials investigated; three such pieces were used for each determination. The rate of temperature change during both heating and cooling tests did not as a rule exceed 3° per minute, and for most of the tests was maintained at from 1° to 2° per minute.

[3] Ber. der Deut. Ker. Gesell., vol. 10, p. 269, June, 1929.
[4] Fizeau, Ann. d. Phys., vol. 128, p. 564, 1866. C. G. Peters and C. H. Cragoe, B. S. Sci. Paper No. 393, 1920. G. E. Merritt, B. S. Sci. Paper No. 485, 1924.

TABLE 1.—*Thermal expansion determinations of bodies composed essentially of "cordierite," $2MgO \cdot 2Al_2O_3 \cdot 5SiO_2$*

[All temperatures in ° C.]

Specimen No.	Composition, determined petrographically	Preparation	Test No.	Linear thermal expansion, expressed as average coefficient [1]			
				R. T.[2] to 100°	R. T.[2] to 200°	Miscellaneous	
						R. T. to—	Coefficient
				×10⁻⁶	×10⁻⁶	°C.	×10⁻⁶
A–1[3]	A, corundum, inclusions in phase C B, crystalline grains with tendency to elongated forms and corroded surfaces. Index between 1.60 and 1.65; probably forsterite. C, cordierite, $2MgO \cdot 2Al_2O_3 \cdot 5SiO_2$. Constitutes the ground mass of the body; low double refraction, twinning common; mean index about 1.53.	Body A. Held at 1,350° for 1 hour	1	0.7	1.1	560	1.9
A–15	Measurably less corundum than in A–1; it occurs as inclusions in the cordierite which constitutes the balance of the body.	Body A. Held at 1,350° for 16 hours	1	.5	.8	660	1.6
A–15a	do	Specimen A–15. Reheated at 950° to 960° for 13 days. Maximum temperatures reached in preceding tests: 310°; 203°; 313°; 505°.	5	.4	.8	400	1.3
A–17	do	Body A. Held at 1,300 to 1,350° for 67 hours. Maximum temperatures reached in preceding tests: 323°; 538°.	3	.2	.5	365	.9
A–3	Approximately 90 per cent cordierite and 10 per cent inclusions, largely corundum.	Body A. Heated in a gas-fired kiln at approximately 1,350° for 3 days and permitted to cool in the kiln.	1			75 400 75–400	−.2 +.9 1.0
A–3a [4]	do	Rods approximately 1¼ cm in diameter and 30 cm long. Preparation same as A–3.	1			75 400 75–400	−.3 +.8 1.0
B–2	90 per cent or more cordierite, balance corundum and a small amount of what appears to be enstatite.	Body B. Heated at 1,345° for 45 hours	1	.5	.9	308	1.1
B–2a	A, cordierite 85 to 90 per cent of total; index 1.53+. Present as well developed grains, larger than in preceding sample. B, spinel occurring as inclusions in phase A. C, very small amount of mullite as groups of fine needles in phase A.	Specimen B–2. Reheated at 1,410° for 17 hours. Maximum temperature reached in test No. 1, 211°.	2		.5	55 55–100 604	−.1 +.2 1.3

[1] Values derived from observations on heating.
[2] R. T.=Room temperature; varied from 20° to 28°.
[3] Chemical analysis by J. F. Klekotka showed SiO_2, 40.7 per cent; R_2O_3, 43.1 per cent; MgO, 15.2 per cent; CaO, 0.05 per cent; ignition loss, 0.15 per cent.
[4] Expansion determined by P. Hidnert using the apparatus and method described in Bureau of Standards Scientific Paper No 524 (1926) by W. Souder and P. Hidnert. R. T.=25°.

TABLE 1.—*Thermal expansion determinations of bodies composed essentially of "cordierite," $2MgO \cdot 2Al_2O_3 \cdot 5SiO_2$*—Continued

[All temperatures in °C.]

Specimen No.	Composition, determined petrographically	Preparation	Test No.	Linear thermal expansion, expressed as average coefficient [1]			
				R. T. to 100°	R. T. to 200°	Miscellaneous	
						R. T. to—	Coefficient
				$\times 10^{-6}$	$\times 10^{-6}$	°C.	$\times 10^{-6}$
C-1	Composed of at least 90 per cent cordierite; index 1.53. The balance is made up of forsterite in irregular, partly dissolved crystals and of corundum in minute rounded grains.	Reagent quality materials. Heated at 1,425° for 20 minutes, ground to pass 80 mesh and reheated at 1,425° for 2 hours.	1	0.5	0.9	400	1.3
C-1a	do	Portion of C-1. Reheated at 750° to 800° for 2 weeks	1		.9		
C-1b	do	Portion of C-1. Reheated at 950° for 4 days. Maximum temperature of test No. 1, 215°.	2		2.4		
C-2a	do	Portion of C-1. Reheated at 890° to 920° for 24 hours	1		1.6		
C-2b	do	Specimen C-2a. Reheated at 1,025° to 1,050° for 3 days	1		1.9		
C-2c	do	Specimen C-2b. Reheated at 1,120° to 1,150° for 2 days	1		2.0		
C-2d	do	Specimen C-2c. Reheated at 1,300° to 1,380° for 3 days	1		1.0		
C-3	Composed of cordierite of index 1.52+ and approximately 20 per cent of an undetermined constituent of index above 1.56 present as fibrous bundles (mullite?) growing from nuclei (corundum?) and always occurring as inclusions in the cordierite.	C-1. Melted at, and quenched from, 1,550° C. Devitrified at 1,100°, time 54 hours. Maximum temperature of test No. 1, 252°.	2	.6	1.0	265	1.1
C-4	Similar to C-3 except that the fibrous crystals appear to be somewhat better developed.	Portion of glass from C-3 devitrified at 1,355°, time 70 hours. Maximum temperatures of preceding test, 392°; 231°; and 440°.	4	−.5		100–200 100–330	.3 .6
C-5	Practically complete devitrification to "unstable" $2MgO \cdot 2Al_2O_3 \cdot 5SiO_2$ of index 1.54+. The ternary compound constitutes 90 to 95 per cent of the total; balance fibrous growths similar to those in C-3.	Portion of glass from C-3 devitrified at 900°; time 4½ days	1	3.4	4.0	317	4.0
D	Some mineral matter other than cordierite present. Occurs as extremely minute prismatic crystals of relatively high index, frequently concentrated along runlets.	Mineral from Orijerfoi, Finland. Supplied by U. S. National Museum, specimen No. 78238. Material is not uniform. Values reported were selected from three duplicate tests.	1	.5	.9	300	1.2

TABLE 2.—*Thermal expansion determinations of some compounds containing elements in Group II (periodic table), including compounds of magnesium other than cordierite*

[All temperatures in ° C.]

Specimen No.	Composition, determined petrographically	Preparation	Test No.	Linear thermal expansion, expressed as average coefficient [1]			
				R. T.[2] to 100°	R. T.[2] to 200°	Miscellaneous	
						R. T. to—	Coefficient
				$\times 10^{-6}$	$\times 10^{-6}$	°C.	$\times 10^{-6}$
E	Forsterite, 80 to 85 per cent $2MgO \cdot SiO_2$	Fusion in electric arc of talc and magnesium carbonate. Maximum temperature of test No. 1, 138°.	2	7.2	8.0	304	8.3
F	Spinel, at least 90 per cent $MgO \cdot Al_2O_3$, balance glass and birefracting material, probably clinostatite or forsterite.	Specimen cut from commercial brick and twice reheated to 1,800° C. Expansion determined by R. A. Heindl (B. S. Technical News Bulletin No. 152, December, 1929).	----	----	----	1,400	8.6
G [3]	Beryl, indices, ω, 1.580; ϵ, 1.573 ($3BeO \cdot Al_2O_3 \cdot 6SiO_2$).	Mineral from San Jose de Bujauba, Minas Geraes, Brazil. U. S. National Museum specimen No. 94218. Maximum temperature of test No. 1, 460°.	2	----	----	53 225	−.2 +.5
G-a [4]	do	Mineral from San Jose de Bujauba, Minas Geraes, Brazil. U. S. National Museum specimen No. 94218. Maximum temperatures of preceding tests, 460°, 225°.	3	1.6	----	225 300	2.1 2.3
H [3]	do	Mineral from Royalston, Mass. U. S. National Museum specimen No. 16626. Maximum temperature of test No. 1, 196°.	2	.3	.7	260	.9
I [3]	do	Mineral from Brazil. U. S. National Museum specimen No. 44586. Maximum temperature of test No. 1, 185°.	2	.3	.7	265	1.0
J [3]	Beryl, indices, ω, 1.588; ϵ, 1.580	Mineral from San Diego County, Calif. U. S. National Museum specimen No. 93926.	1	.9	1.3	----	----
J-a [4]	do	Mineral from San Diego County, Calif. U. S. National Museum specimen No. 93926. Maximum temperature of preceding test, 200°.	2	1.6	----	225 300	2.2 2.2
K	Zinc orthosilicate, approximately 95 per cent $2ZnO \cdot SiO_2$, balance glass.	Prepared by E. N. Bunting (B. S. Jour. Research, vol. 8 (2) (R. P. 413), p. 279, 1932), and obtained by devitrification. Melting point, 1,510° C.	1	.8	1.2	350	1.6
L	Zinc aluminate, 38 per cent ZnO, 55 per cent Al_2O_3, balance mostly oxides of iron.	Mineral supplied by U. S. National Museum. Maximum temperature of test No. 1, 240°.	2	6.4	7.3	525	7.7
M	Celsian, approximately 90 per cent $BaO \cdot Al_2O_3 \cdot 2SiO_2$.	$BaCO_3$ and kaolin heated for 2½ hours at from 1, 550° to 1,580° C.	1	2.7	3.1	400	3.4
N	Anorthite, approximately 95 to 97 per cent $CaO \cdot Al_2O_3 \cdot 2SiO_2$.	Repeated heating of reagent quality materials (at temperatures about 50° below the melting point of anorthite) and regrinding. Prepared in the cement section of the Bureau of Standards.	1	3.5	4.0	300	4.3
O	Dicalcium aluminum silicate, approximately 95 per cent $2CaO \cdot Al_2O_3 \cdot SiO_2$ in well-formed crystals.	Reagent quality materials wet ground. Reheated twice, maximum temperatures 1,300° and 1,570°, respectively. Prepared by H. Insley.	1	7.3	8.0	400	8.1
P	Calcium metasilicate, >95 per cent α $CaO \cdot SiO_2$	Same as specimen N	1	10.9	11.7	----	----
Q	Corundum, over 99 per cent Al_2O_3	Commercial electric furnace product	1	5.9	7.1	600	7.9
R	Mullite, almost entirely $3Al_2O_3 \cdot 2SiO_2$; a small percentage of glass and corundum present.	Fusion of alumina and silica. Expansion determined by R. A. Heindl (B. S. Tech. News Bull. No. 139, November, 1928).	----	----	----	1,100	5.3

[1] Derived from observations on heating. [2] R. T.=Room temperature; varied from 20° to 28°. [3] Parallel to c axis. [4] Perpendicular to c axis.

TABLE 3.—*Values indicating reproducibility of results*

Values given are the total expansion in μ per meter from room temperature to t_o

Specimen No.	t_o °C.	First test	Second test	Third test	Fourth test
		μ	μ	μ	μ
A-17	100	5	15	15	15
	155	60	60	50	45
	255	170	150	140	----

t_o °C.	A-1[1]		A-3[1]		C-1[1]	
	(a)	(b)	(a)	(b)	(a)	(b)
100	50	45	10	5	40	40
200	200	195	80	90	150	160
300	365	380	180	190	295	305
400	590	610	----	----	480	500
560	1,000	1,020	----	----	----	----

[1] Duplicate specimens.

The reproducibility of results is indicated by the data in Table 3.

III. RESULTS

1. CORDIERITE

The first expansion determinations were made on specimens of body A. Results are summarized in Table 1 and shown graphically in Figure 1. Since cordierite ($2MgO \cdot 2Al_2O_3 \cdot 5SiO_2$)[5] was the predominant phase in all of the specimens of the A series, the next series (B and C, Table 1) were prepared of mixtures in the proper proportions to produce this compound. However, in no case did the product contain more than approximately 90 to 95 per cent of cordierite. When heated at about 1,350° the principal impurities in the talc bodies (A–3, Table 1) were corundum (Al_2O_3) and forsterite ($2MgO.SiO_2$), while heating at higher temperatures for long periods of time (B–2a) evidently produced some decomposition of the ternary compound with the resultant formation of small amounts of spinel ($MgO \cdot Al_2O_3$) and mullite ($3Al_2O_3 \cdot 2SiO_2$). Prolonged heating of the specimens of series C also promoted the growth of bundles of fibrous crystals, apparently mullite, which originated from minute rounded grains of corundum.

Thermal expansions of the minor constitutents (forsterite, spinel, corundum, and mullite) were determined by test or taken from values given in the literature (Table 2). Their expansions are all considerably higher than the expansions of the specimens which are composed predominantly of "cordierite" (as distinguished from the "unstable" forms of $2MgO \cdot 2Al_2O_3 \cdot 5SiO_2$ by refractive indices and other optical properties)[6] and there was no indication of contraction during heating below 100° for these materials. It is believed that the low expansions observed are characteristic of bodies composed essentially of cordierite.

[5] G. A. Rankin and H. E. Merwin, Am. J. of Sci., vol. 45, p. 301, 1918. E. A. Wulfing and L. Oppenheimer, Ber. der Heidl. Akad. der Wissen, No. 10, 1914.

[6] See footnote 5.

The difference in expansion of specimens A–3 and C–1 (Table 1), both of which contain about 90 per cent cordierite, can not be explained satisfactorily as due to the effect of the impurities alone. That there may be undetermined differences in the crystal structure

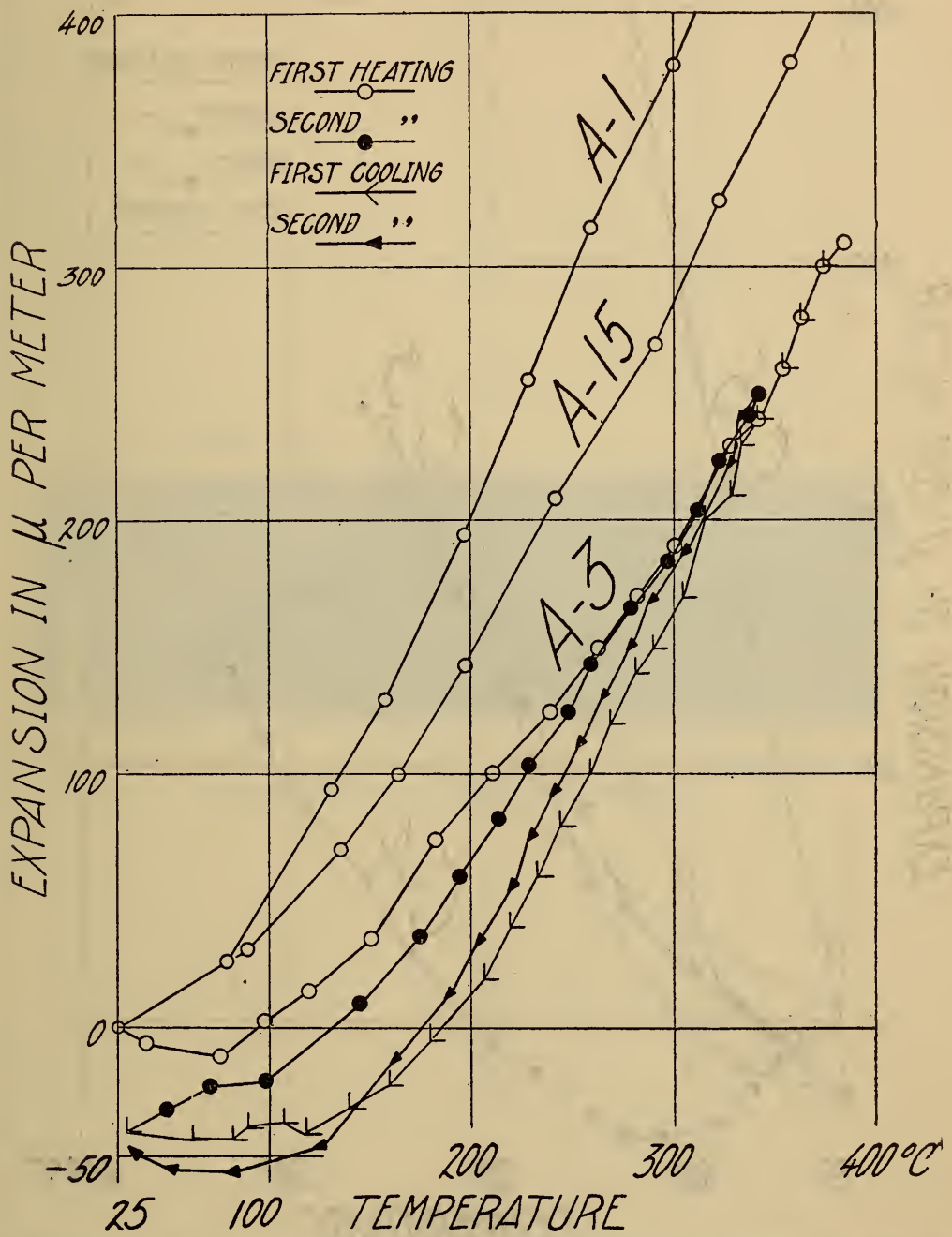

FIGURE 1.—*Thermal expansion curves for cordierite specimens of series A heated at 1,350° C. for one hour (A–1), 16 hours (A–15), and for 3 days (A–3)*

or composition of the cordierite is indicated by Rankin and Merwin,[7] who have observed considerable difference in indices of refraction of the cordierite from samples which appear optically homogeneous, but which vary somewhat in composition. This they attribute to solid solution of SiO_2 in the cordierite. Slight difference in the indices

[7] See footnote 5, p. 40.

of refraction were observed in some of the samples of cordierite used in this investigation, as is evidenced by B–2a and C–3.

The "unstable" form (C–5) with the composition $2MgO \cdot 2Al_2O_3 \cdot 5SiO_2$ was obtained by the method used by Rankin and Merwin;[8] that is,

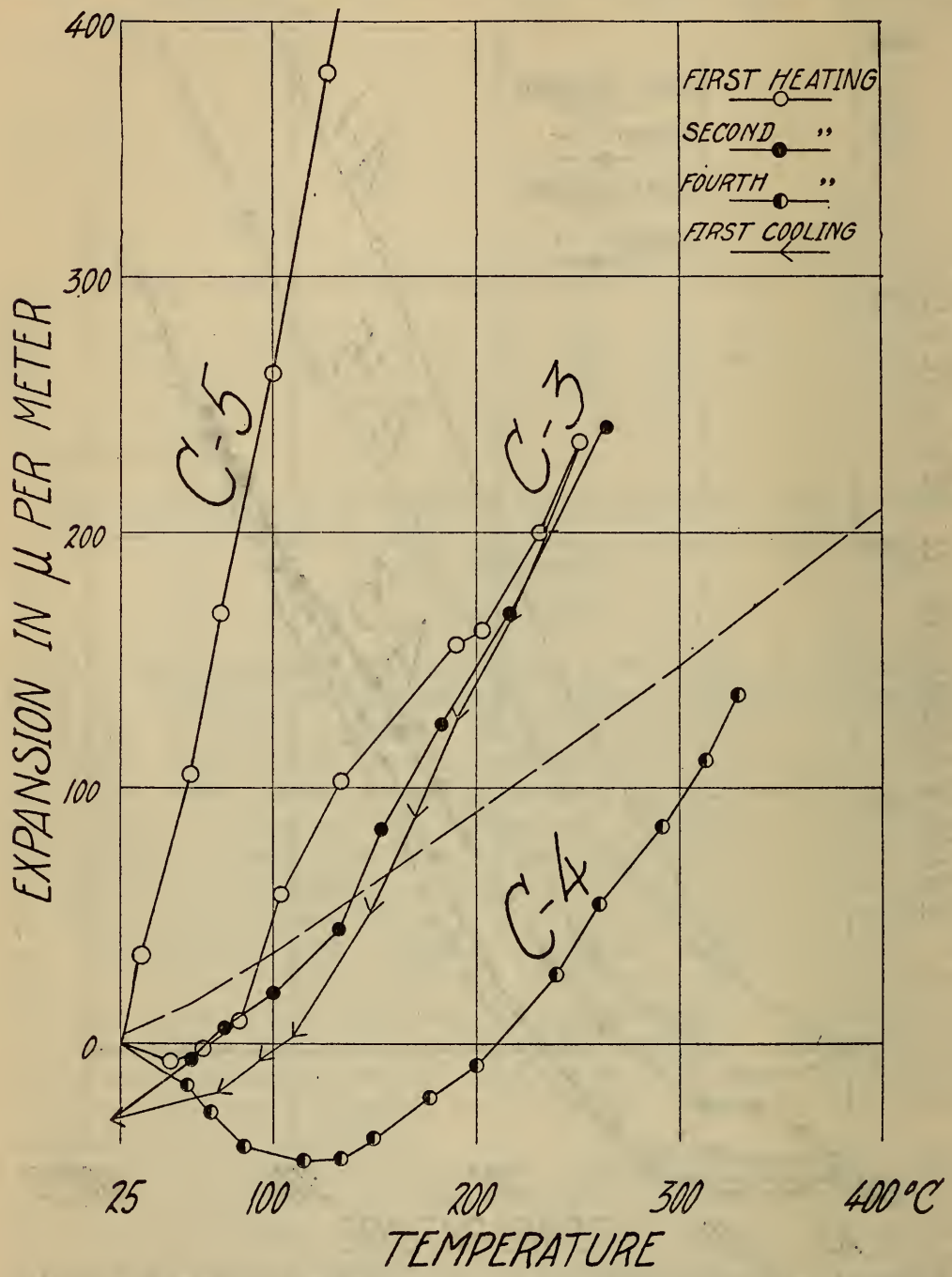

FIGURE 2.—*Thermal expansion curves for cordierite specimens of series C prepared from the glass by devitrification at 900° C. (C–5), 1,100° C. (C–3, and 1,355° C. (C–4)*

The dashed line is for fused quartz and is drawn from data in B. S. Sci. Paper No. 524.

by heating a glass of the same composition at about 900° for a considerable time. The product obtained corresponds in indices of refraction and other optical properties to that described by them. Its

[8] See footnote 5, p. 40.

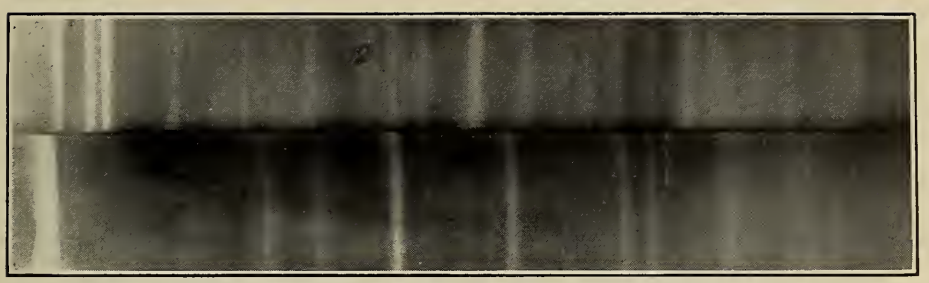

FIGURE 3.—*X-ray patterns of the stable (top) and unstable (bottom) forms of* $2MgO \cdot 2Al_2O_3 \cdot 5SiO_2$ *(cordierite)*

thermal expansion (C–5, Table 1 and fig. 2) is unquestionably considerably higher than that of cordierite. The increased expansion of specimens C–1b and C–2c after reheating at from 900° to 1,150° could not be duplicated with the talc body A–15. This increased expansion can not be attributed to the unstable form of the 2:2:5 compound, because neither petrographic examinations nor X–ray patterns of the reheated specimens C–1b and C–2c showed its presence. That the X–ray photograph would have shown the pattern of the unstable compound, if present in sufficient quantity to affect the expansion, seems probable from the marked difference in the two patterns. (Fig. 3.)

The small permanent contraction of about 40μ per meter evidently caused by the first heating (specimen C–3 in fig. 1) is characteristic of this form and in one case was noted to a lesser degree (5μ to 10μ per meter) after a specimen (A–17) had been heated and cooled four times. It was also noted that the cordierite specimens may have a slightly higher rate of contraction during cooling than of expansion during heating, in the temperature range above 100°, even though there is no measurable permanent length change. This is typified by the second heating and second cooling curves for A–3. (Fig. 1.)

The results do not permit the presentation of thermal expansion curves, or of coefficients, as correct for a compound of the definitely determined composition $2MgO \cdot 2Al_2O_3 \cdot 5SiO_2$. It is fairly evident, however, that (*a*) the crystalline phase observed as constituting the bulk of the specimens of series A, B, and C is the same as the stable form of the ternary compound identified by Rankin and Merwin [9] having the approximate composition 2:2:5; (*b*) the thermal dilatation of this stable form of the ternary compound is remarkably low; it may contract slightly during heating from about 20° to 80°; and the average linear expansion, when heated from 20° to 400°, is about 1 μ per meter per °C. (equivalent to a coefficient of 0.000001); (*c*) the average linear change for the temperature range of 20° to 100° is much lower than for any other equivalent range; and (*d*) the expansion of the specimen of the unstable form tested is unmistakably higher than that of the stable.

(a) GENERAL COMMENTS

The specimens of series A and B were uniformly light buff to gray in color and of a firm but open texture. The gain in weight (water absorption) of an A–3a specimen (Table 1) resulting from autoclaving it in water for one and one-half hours at a steam pressure of 150 lbs./in.^{2} was 25.8 per cent; there was no measurable length change or "moisture expansion" over a 10 cm length. The specimens of series C prepared either by devitrification, or by heating at 1,425°, resembled opaque white glass which was very difficult to pulverize with mortar and pestle, and pieces could be heated to a red heat and plunged into cold water without being visibly affected. Specimens of the glass (series C) heated at 900° for five hours or less showed no devitrification. Heating at 900° for four and one-half days produced the unstable, or high expanding, form (C–5, fig. 2) and heating at 950° for two days (or at higher temperatures, C–3 and C–4, fig. 2) produced the stable form. At 1,380° the glass devitrified completely to the stable form in 15 minutes.

[9] See footnote 5, p. 40.

2. COMPOUNDS OTHER THAN CORDIERITE

Of the other compounds investigated (Table 2 and figs. 4 and 5) the three having the lowest average expansion are beryl (*G*, *H*, *I*, and *J*), zinc orthosilicate (*K*), and celsian (*M*). The data for the four specimens of beryl are presented in some detail, partly because of their very low expansions and partly because beryl has received some attention, as a material of low thermal expansion, from previous investigators.[10] Both cordierite and beryl may contract slightly when heated from 20° to 100° and their average coefficients are not greatly different. However, on first heating and cooling beryl it is likely to show a permanent expansion of 30 to 40 μ per meter. The expansion

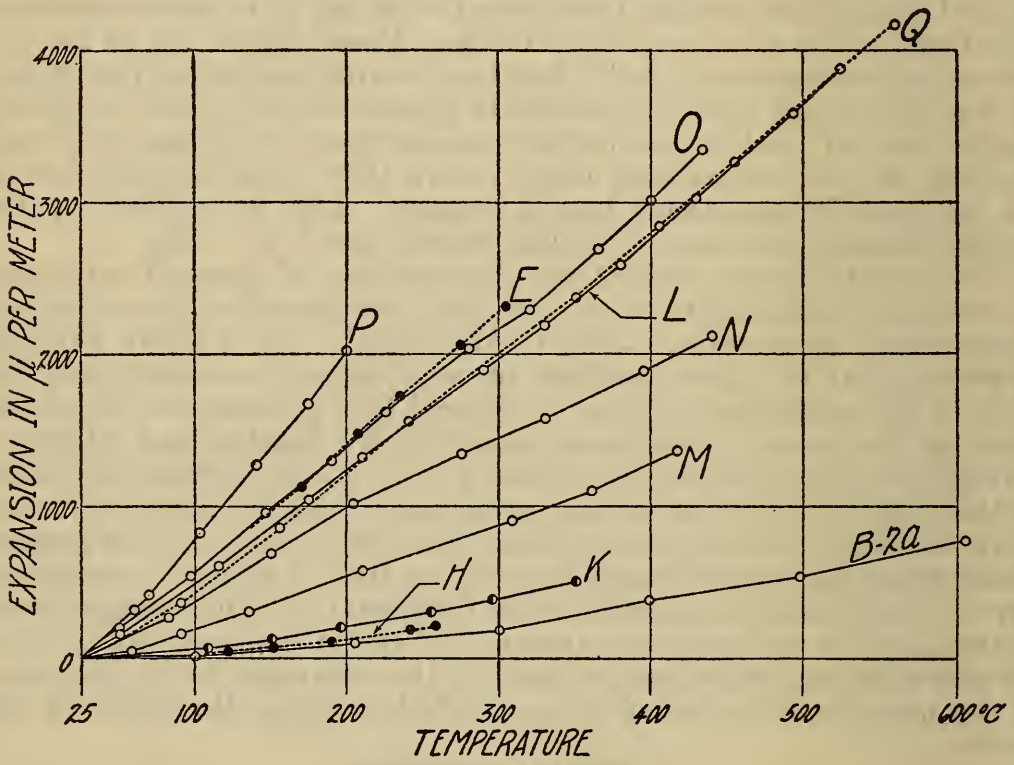

FIGURE 4.—*Thermal expansion curves of some of the materials described in Table 2, E, forsterite; K, zinc orthosilicate; L, zinc aluminate; M, celsian; N, anorthite; O, dicalcium aluminum silicate; P, calcium metasilicate*

Curves for a cordierite specimen (B–2a, Table 1) and for a beryl specimen (*H*) are included for comparative purposes.

curves for the "stabilized" specimens (that is, curves obtained after two or more tests) are given in Figure 5. Worthy of note are (*a*) the similarity in behavior of specimens *G*, *H*, and *I*, which have the same indices (Table 2); (*b*) the somewhat higher rate of expansion of J, which has higher indices; and (*c*) the fact that the expansion perpendicular to the *C* axis is relatively much higher than the expansion parallel to the same axis and is practically identical for both *G* and *J* specimens.

Several attempts to produce a specimen composed chiefly of some one crystalline silicate of cadmium (which has the same crystal habits as zinc, magnesium, and beryllium) were unsuccessful. The proper

[10] H. Fizeau, Compt. rend., T. LXVI, p. 1005, 1868. A. V. Bleininger and F. H. Riddle, J. Am. Ceram. Soc., vol. 2, p. 564, 1919. Robert Twells, jr., J. Am. Ceram. Soc., vol. 5, p. 228, 1922.

mixture of CdO and SiO_2 to form $CdO \cdot SiO_2$, when heated at 1,425° showed no evidence of reaction; after heating at 1,550° there was evidence of reaction, but the material rapidly fell to a powder when removed from the furnace. A mix to form $2CdO \cdot SiO_2$ was heated to a

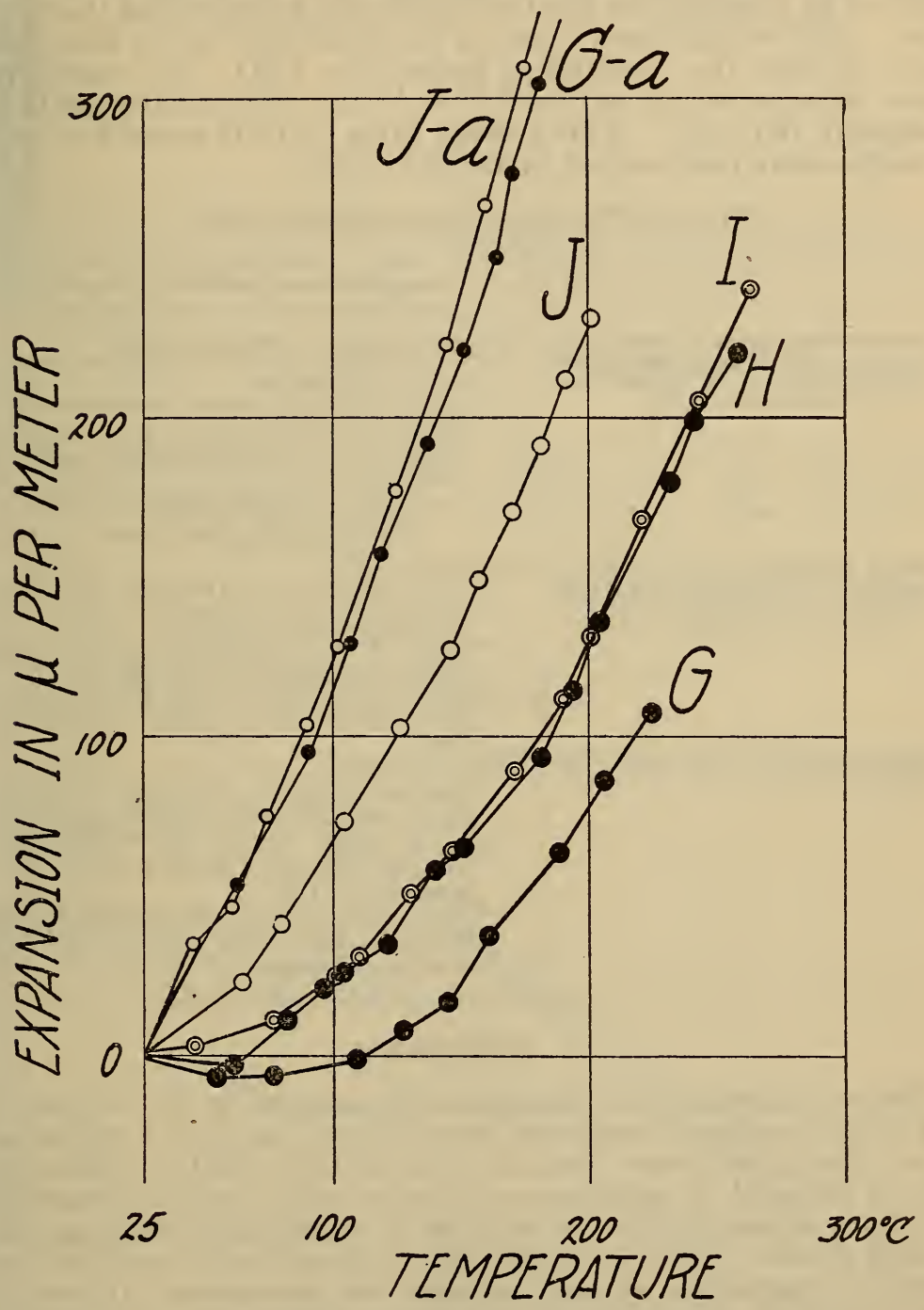

FIGURE 5.—*Thermal expansion curves for specimens of beryl described in Table 2*

J-a and *G*-a were determined perpendicular, the others were determined parallel, to the *C* axis.

maximum temperature of 1,600°. The product is described in Table 4. This material, even when quenched in water from 1,600°, also fell to a powder and no thermal expansion observations were attempted. Glasses having the calculated compositions $CdO \cdot Al_2O_3 \cdot 2SiO_2$ and

$2CdO \cdot 2Al_2O_3 \cdot 5SiO_2$ were obtained when the respective mixtures were heated at 1,450°. They were devitrified at approximately 1,250° and the products are described in Table 4. The average coefficient of expansion for the temperature range 25° to 300° was found to be 7.0×10^{-6} for the 1:1:2 glass and 6.5×10^{-6} for the 2:2:5 glass. Substituting these values in the formula given by Hall [11] one may calculate the "expansion factor" for CdO. The calculated values obtained in this way were 97 and 104×10^{-9}, the average being practically 100×10^{-9}. This average value for CdO would not apply to temperature ranges other than 25° to 300°.

TABLE 4.—*Properties of some cadmium silicates*

	Composition, determined petrographically
Calculated composition, $2CdO \cdot SiO_2$ *Preparation*—Wet ground mixture of CdO and SiO_2 heated at 1,550° to 1,600° C. for 45 minutes and cooled rapidly.	Two phases, neither of which predominates: Phase A. Index just above 1.7 (about 1.71) with very low or no birefringence. Phase B. Isotropic and occurs as inclusions in phase A; the index is much lower than 1.7. (NOTE.—In Sprechsaal, vol. 52, p. 256, 1919, F. M. Jaeger and H. S. van Klooster report the following values: $2CdO \cdot SiO_2$, melting point 1,243° to 1,252° C.; indices N_1 and $N_2 > 1.739$. $CdO \cdot SiO_2$, melting point 1,242±0.5° C.; indices N_1 and $N_2 > 1.739$)
Calculated composition, $CdO \cdot Al_2O_3 \cdot 2SiO_2$ *Preparation*—Wet ground mixture of CdO and Georgia kaolin melted to a clear glass at 1,450° C. and devitrified at 1,250° C.	Three phases present: Phase A. Probably the most abundant, occurs as irregular crystals of very low double refraction (<0.005) with a mean index of about 1.65. Phase B. Either glass or isotropic crystals occurring usually as interstitial material between grains of phase A. Index lies between 1.61 and 1.62. Phase C. Minute rounded grains of high index and high double refraction occurring as inclusions in phase A.
Calculated composition, $2CdO \cdot 2Al_2O_3 \cdot 5SiO_2$ *Preparation*—Same as for $CdO \cdot Al_2O_3 \cdot 2\ SiO_2$.	Three phases present: Phase A. Most abundant and occurs with some faces (probably prismatic) well developed. Crystals are biaxial, very large optic axial angle (approximately 90°) and indices: $\alpha = 1.575 \pm 0.003$, $\gamma = 1.590 \pm 0.003$. Phase B. Isotropic, probably glass. Somewhat less abundant than phase A and index variable but between 1.615 and 1.620. Phase C. Least abundant; occurs as irregular crystalline growths showing a tendency to dendritic forms. Double refraction very low (probably 0.005 or less), mean index 1.65±0.005.

IV. SUMMARY

The low expansion of a magnesia body reported by W. M. Cohn [12] is a characteristic of cordierite (the "stable" form of a compound having the approximate formula $2MgO \cdot 2Al_2O_3 \cdot 5SiO_2$). This form may be prepared by sintering a mixture of talc, clay, and corundum at 1,350°, although the time required is considerably shortened by heating at from 1,400° to 1,425°. At temperatures above 1,425° to 1,450° decomposition of the cordierite will take place. It may be formed also by devitrification of a glass of the proper composition at temperatures above 950° and below about 1,425°.

Zinc orthosilicate, celsian or barium feldspar, and beryl also appear worthy of further consideration by those interested in the development of bodies having low coefficients of thermal expansion.

WASHINGTON, February 19, 1932.

[11] J. Am. Ceram. Soc., vol. 13 (3), p. 182, March, 1930. [12] See footnote 2, p. 35.